SF 298 MASTER COPY KEEP THIS COPY FOR REPRODUCTION PURPOSES

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
April 1996

3. REPORT TYPE AND DATES COVERED
Technical

4. TITLE AND SUBTITLE
Effect of pressure and Heat Flux on Bubble Departure Diameters and Bubble Emission Frequency

5. FUNDING NUMBERS
DAAH04-95-1-0250

6. AUTHOR(S)
Sharma, Parashu R., Lee, Angela, Harrison, Tameka, Martin, Ebony, and Neighbors, Krisha

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Grambling State Uhiversity
Department of Mathematics and Computer Science
Carver Hall, Room # 137
GRAMBLING, LA 71245

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
ARO 34157.25-MA-ISP

11. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12 b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The bubble departure diameters and bubble emission frequency have been calculated for the nucleate pool boiling data of Engelhorn for many refrigerants over a wide range of heat flux and pressure. The pressure ranged from 0.019 bar to 10.55 bar and the heat flux ranged from 102,000 W/m^2 to 1,000 W/m^2. The bubble departure diameters were calculated using Laplace Equation and the bubble emission frequency were calculated using the equations of Sharma et al. The study reveals that the bubble departure diameter increases as the pressure decreases. The bubble emission frequency is the strong function of heat flux. The frequency also increases with increase in pressure, however, not as strong as it increases with heat flux. An increase in the size of the bubble makes the heat transfer process sluggish. An increase in the bubble emission frequency leads to higher heat transfer rates due to enhanced turbulence in the process. Therefore, the heat transfer coefficients are lower at lower pressures and higher at higher pressures and heat fluxes.
* Work supported by Army Research Office and Office of Naval Research

14. SUBJECT TERMS
Pool Boiling, Heat Transfer in Two Phase

15. NUMBER IF PAGES
26

16. PRICE CODE

17. SECURITY CLASSIFICATION OR REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Enclosure 1

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

EFFECT OF PRESSURE AND HEAT FLUX ON BUBBLE DEPARTURE DIAMETERS AND BUBBLE EMISSION FREQUENCY

Tameka Harrison, Angela Lee,
Krisha Neighbors & Ebony Martin

Advisor: Dr. Parashu Sharma

Grambling State University
Department of Math & Computer Science

6th Annual P. L. Young Research Symposium

APRIL 18, 1996

Sponsored by
Army Research Office &Office of Naval Research

INTRODUCTION

Nucleate pool boiling is a very efficient heat transfer process for removing heat from a heat transfer surface. It is one of the important mechanisms to remove heat from electronic and microelectronic equipment, nuclear reactors, space vehicles, and other heat transfer equipment used in process, refrigeration, and food industry. In order to understand the process of heat transfer it is important to understand the underlying mechanism of the process. An analytical model consistent with the requirements of nucleate pool boiling heat transfer requires mathematical expressions for:

1) Number of Nucleation Sites

2) Bubble Departure Diameters

3) Bubble Growth Rates

4) Bubble Emission Frequency

The purpose of this work is to calculate the bubble departure diameters and bubble emission frequency for the data of Engelhorn. Engelhorn has conducted experiments for a wide variety of refrigerants and for a wide range of heat flux and pressure. For the calculation of bubble departure diameters we used Laplace Equation and for the bubble emission frequency we used the equations earlier developed by Sharma et al.

ANALYSIS:

Bubble Departure Diameter

The bubble departure diameters are obtained by analyzing the forces on a typical growing bubble. Two forces are important; surface tension and the buoyancy.

Surface Tension Force = $\pi D \sigma$

Buoyancy Force = $\frac{\pi}{6} D^3 \, [\rho_l - \rho_v] \, g$

At equilibrium, the two forces are equal.

$$\frac{\pi}{3} D^3 \, [\rho_l - \rho_v] \, g = \pi D \sigma$$

$$D = C \sqrt{\frac{\sigma}{[\rho_l - \rho_v] g}} \qquad (1)$$

Equation (1) is known as the Laplace Equation. The equation shows that bubble departure diameters is the function only of physical properties which are constant for a given pressure.

Bubble Emission Frequency

In nucleate pool boiling heat transfer, bubble emission frequency (f) is composed of two periods;

1) Growth period (θ_d) and 2) Waiting period (θ_w)

Therefore, bubble emission frequency f is:

$$f = \frac{1}{(\theta_d + \theta_w)}$$

The equations were earlier developed for the growth period and the waiting period. From those equations, the final equations for the bubble emission frequency are:

for $Ja \leq 100$

$$f = \frac{1}{\frac{[133.3/P]^2 [\sigma/(\rho_l - \rho_v)g}{\pi \alpha_l Ja^2} + \frac{0.867}{\alpha_l}[\frac{k_l \Delta T_w}{q_w}]^2}$$

and for $Ja > 100$

$$f = \frac{1}{\frac{[133.3/P]^2 [\sigma/(\rho_l - \rho_v)g}{25\alpha_l Ja^{3/2}} + \frac{0.867}{\alpha_l}[\frac{k_l \Delta T_w}{q_w}]^2}$$

The above equations reveal that for a given liquid and at a given pressure the bubble emission frequency is a function of heat flux, and physico-thermal properties . These equations were used to calculate the bubble emission frequency for the data of Engelhorn.

RESULTS

The bubble emission frequency were calculated for refrigerants R-11, R-12, R-13, R-13B1, and R-22. Table-1 shows the values of pressures for each fluid and the range of heat flux.

TABLE-1

REFRIGERANTS	HEAT FLUX, W/m2	PRESSURE, Bar
R-11	1,000 to 83,000	0.019,0.028, 0.503, & 0.991
R-12	100 to 102,000	0.25, 0.50, 1.0 &1.80
R-13	200 to 84,000	2.80, 4.55, 7.35 &10.55
R-13B1	200 to 96,000	0.78,1.51& 5.60
R-22	200 to 99,000	0.39,0.84 & 2.15

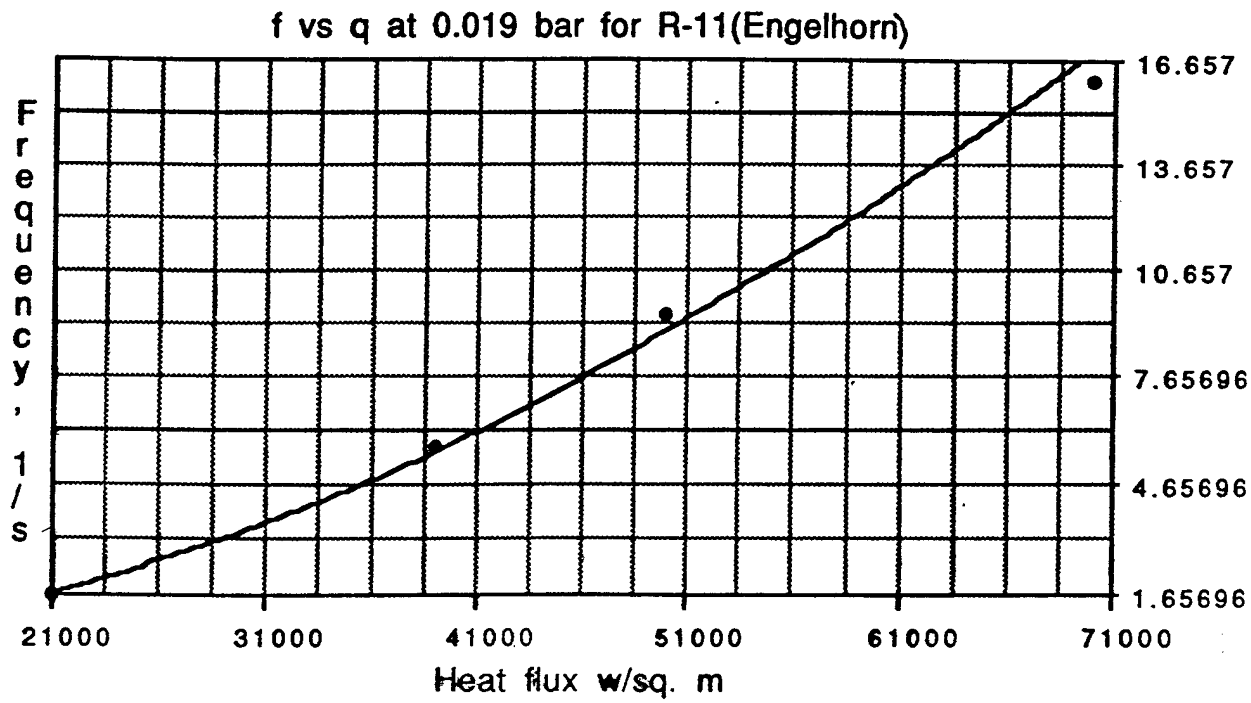
Graphs were prepared for the frequency as a function of heat flux. The study reveals that bubble frequency is the strong function of heat flux. It increases with increase in heat flux. The inspection of these graphs also reveal that bubble frequency also is a function of pressure. An increase in pressure shows increase in bubble emission frequency. An increase in bubble emission frequency with increase in heat flux and pressure implies that heat transfer rates in boiling will be enhanced with increase in heat flux and pressure.

The calculations also reflect the effect of pressure on bubble departure diameter. The bubble departure diameters decrease with increase in pressure. This functional relationship is shown by making plots of bubble departure diameter as a function of pressure for five refrigerants investigated. The increase in the bubble departure diameter with decrease in pressure will manifest as reduction in heat transfer coefficients as pressure decreases.

CONCLUSIONS

1. The study reveals that the bubble emission frequency is a strong function of heat flux. It also increases with increase in pressure.

2. Bubble departure diameters are the function only of pressure for a given liquid. The bubble departure diameter decreases with increase in pressure.



Report Created: 04-17-1996 11:19:54 AM

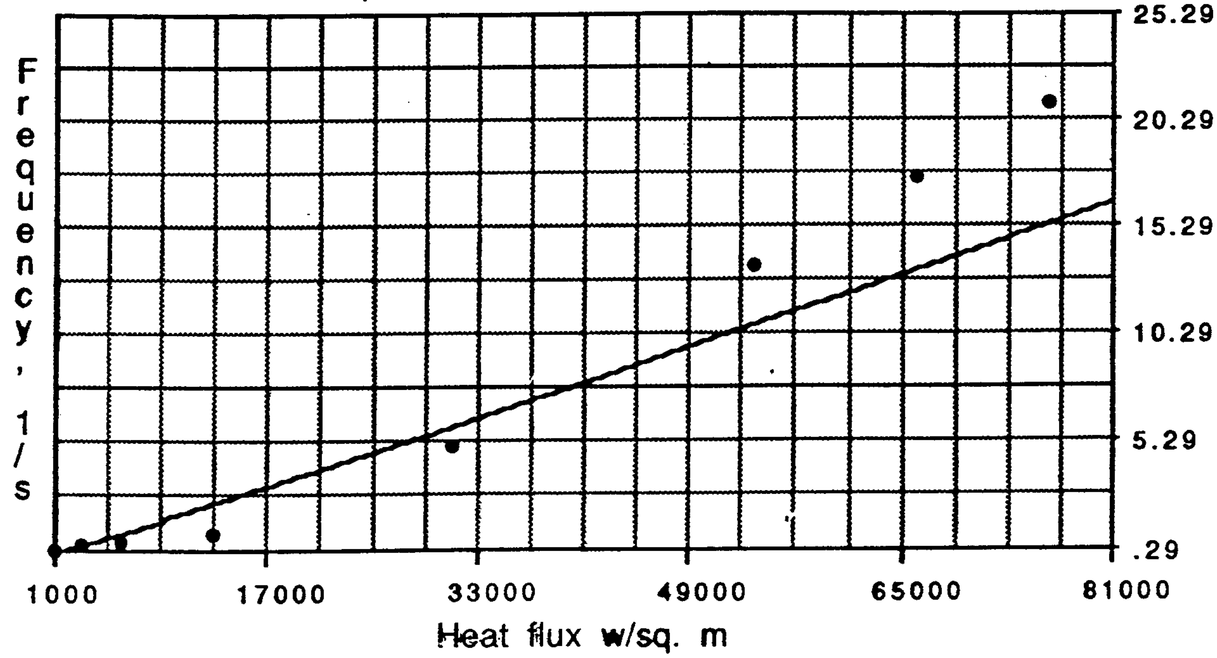
Power Curve Fit
Pts Plotted = 4 Offscale Pts = 0

Regression Equation:
Y = 9.80831E-09 X ^ 1.90664

Correlation Coefficient = .998636

X-axis file: r11_heatflux_1
Y-axis file: r11_freq_1

f vs q at 0.028 bar for R-11(Engelhorn)



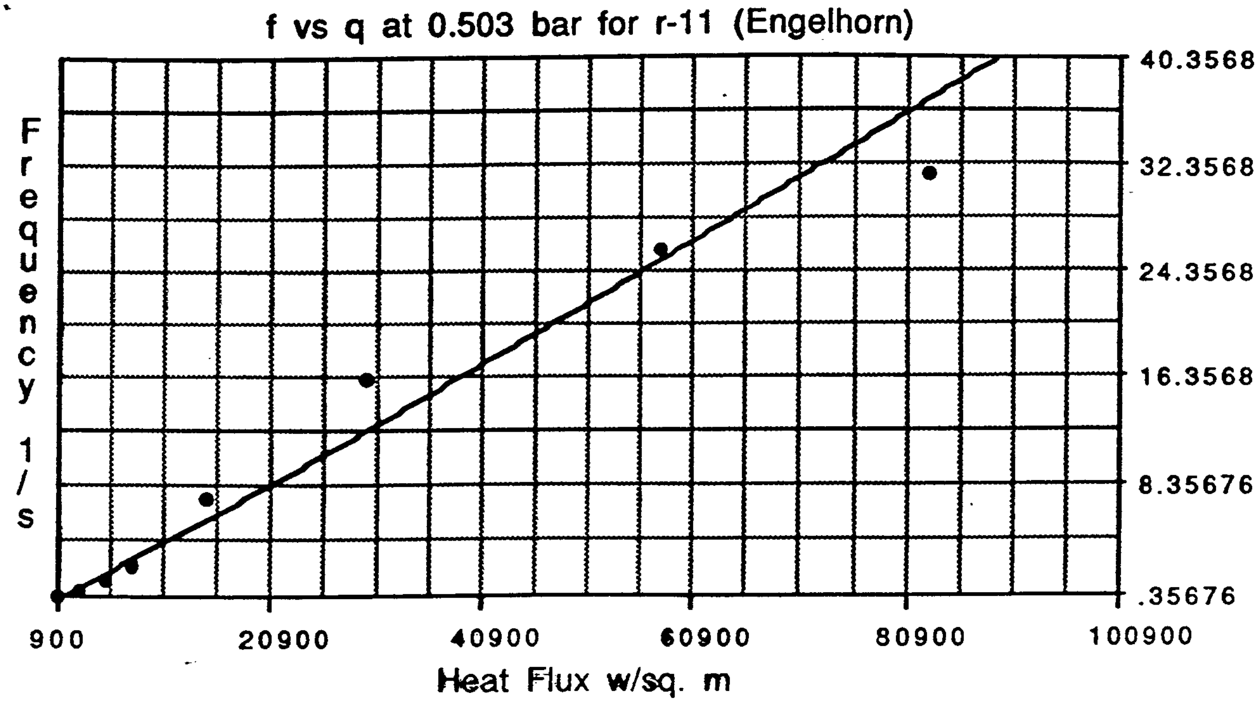
Report Created: 04-17-1996 11:19:54 AM

Power Curve Fit
Pts Plotted = 8 Offscale Pts = 0

Regression Equation:
Y = 1.03267E-04 X ^ 1.05954

Correlation Coefficient = .96324

X-axis file: r11_heatflux_2
Y-axis file: r11_freq_2



Report Created: 04-17-1996 8:29:52 AM

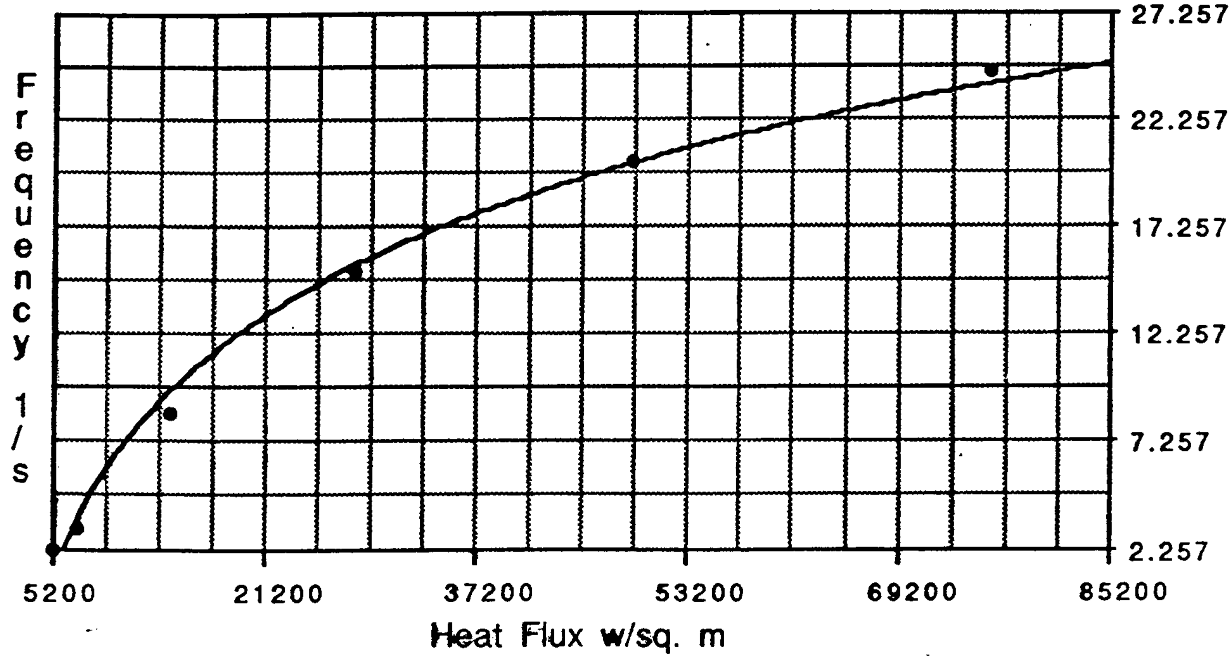
Power Curve Fit
Pts Plotted = 8 Offscale Pts = 0

Regression Equation:
Y = 1.7335E-04 X ^ 1.08382

Correlation Coefficient = .990954

X-axis file: r-11_q_x-axis
Y-axis file: r-11_f_y-axis_0.503

f vs q at 0.991 for R-11 (Engelhorn)



Report Created: 04-17-1996 8:23:58 AM

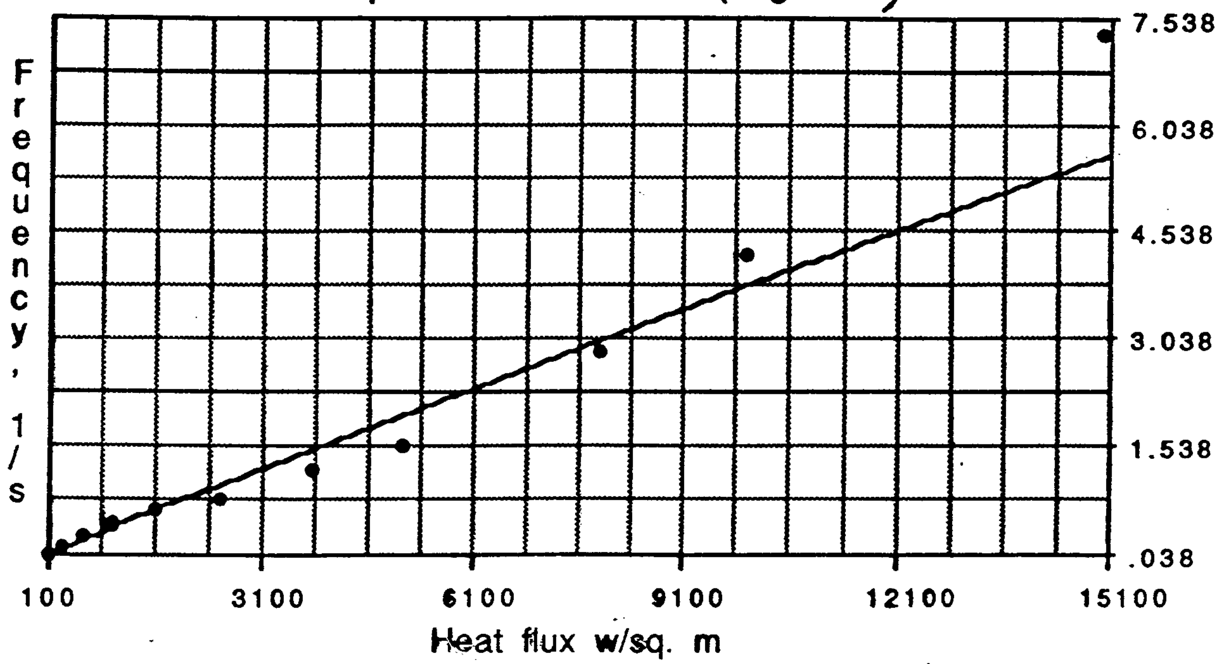
Logarithmic Curve Fit
Pts Plotted = 6 Offscale Pts = 0

Regression Equation:
Y =-71.4429 + (8.48594) LNX

Correlation Coefficient = .99651

X-axis file: r-11_0.991_x-axis
Y-axis file: r-11_0.991_f_y-axis

f vs q at 0.25 bar for R-12(Engelhorn)



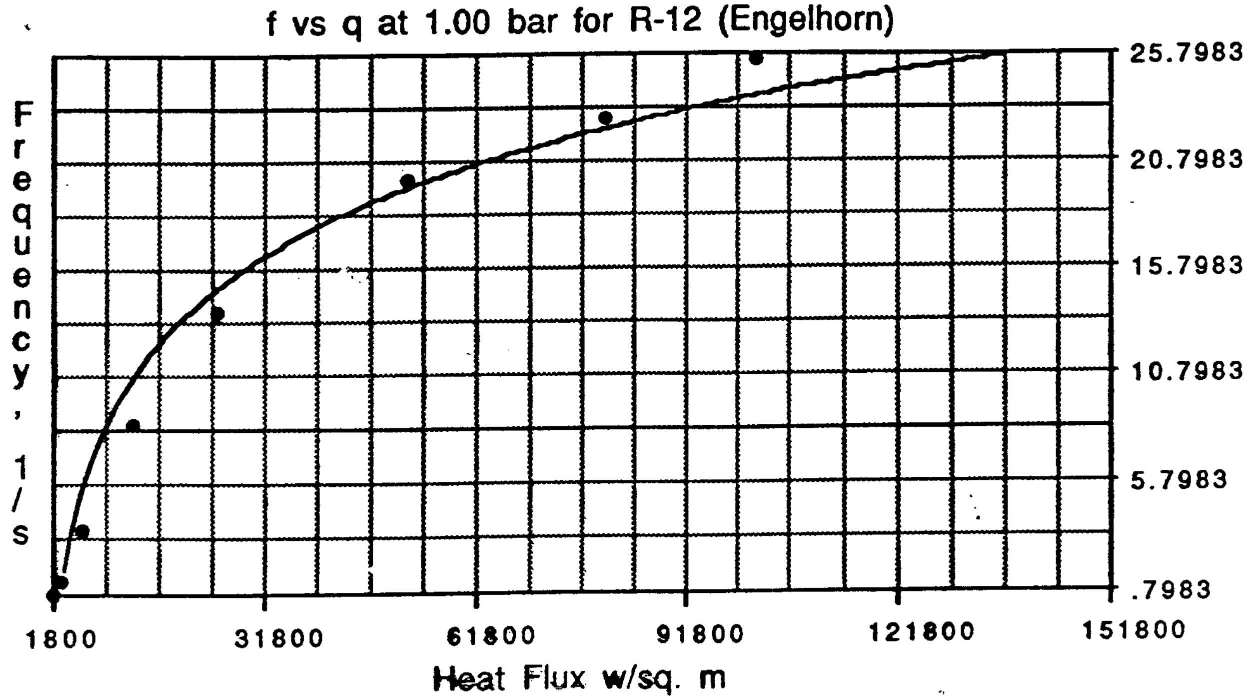
Report Created: 04-17-1996 11:19:54 AM

Power Curve Fit
Pts Plotted = 11 Offscale Pts = 0

Regression Equation:
Y = 4.98357E-04 X ^ .969699

Correlation Coefficient = .992982

X-axis file: r12_heatflux_1
Y-axis file: r12_freq_1



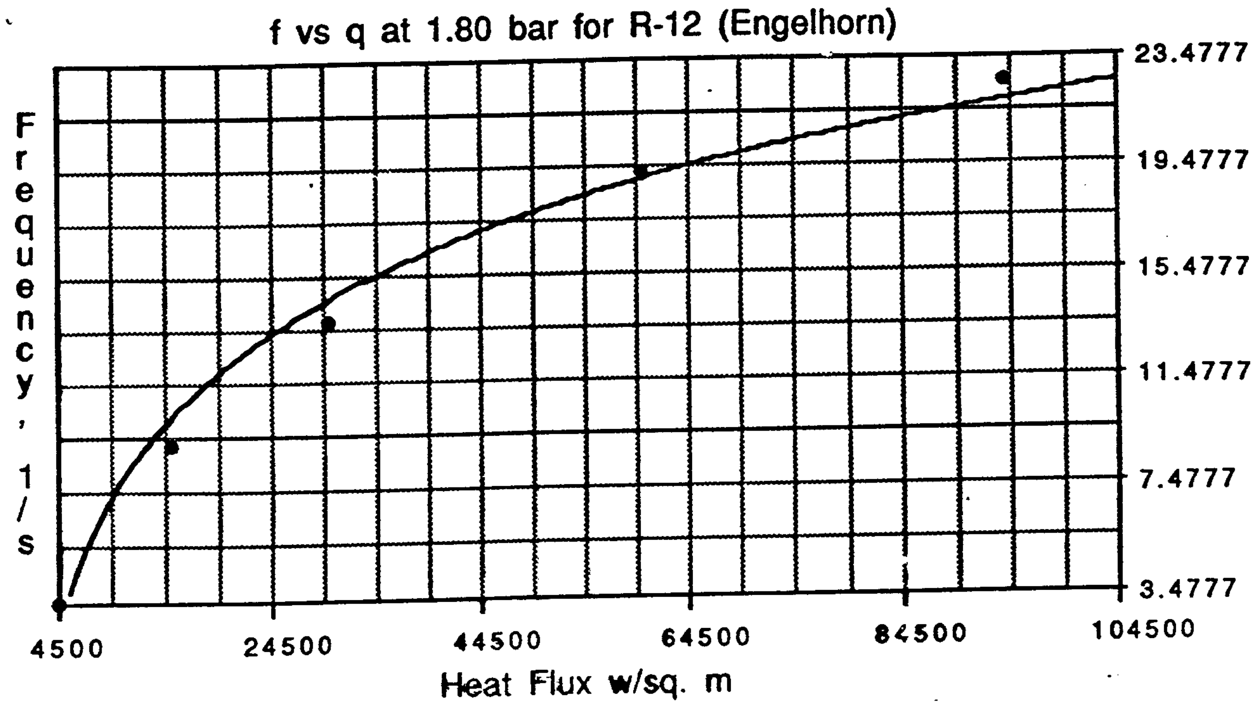
Report Created: 04-17-1996 10:13:31 AM

Logarithmic Curve Fit
Pts Plotted = 8 Offscale Pts = 0

Regression Equation:
Y =-49.7848 + (6.38598) LNX

Correlation Coefficient = .984858

X-axis file: r12_heatflux
Y-axis file: r12_freq



Report Created: 04-17-1996 10:13:31 AM

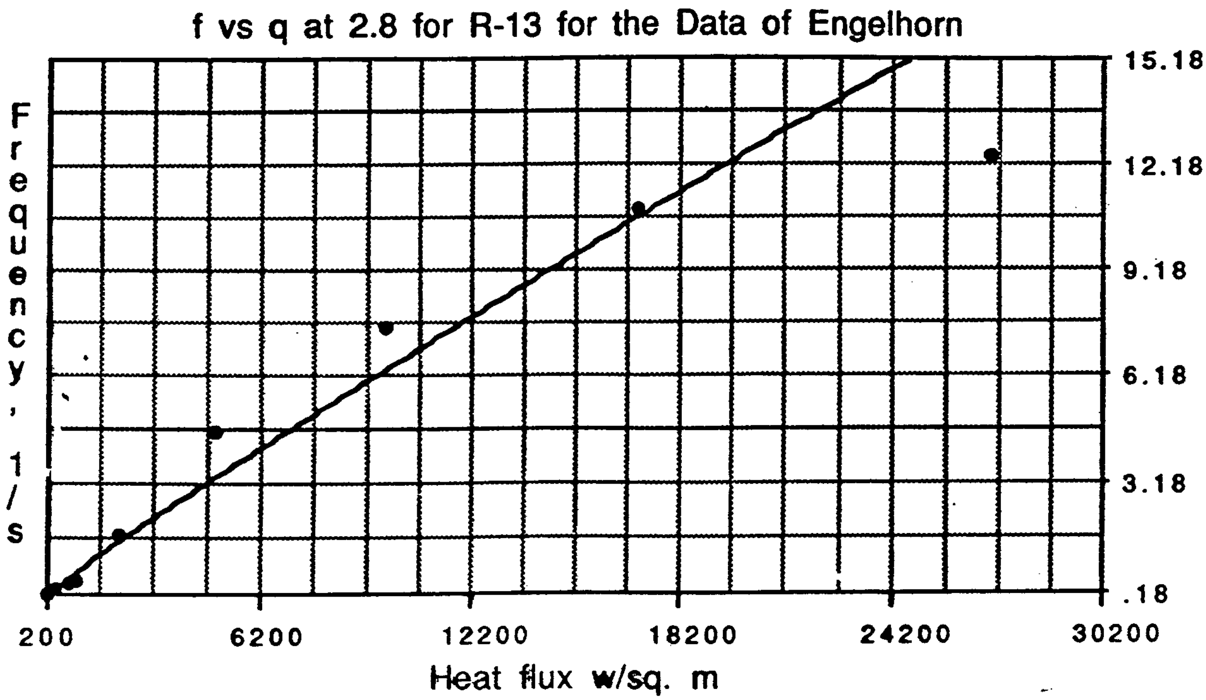
Logarithmic Curve Fit
Pts Plotted = 5

Offscale Pts = 0

Regression Equation:
Y =-50.8725 + (6.3533) LNX

Correlation Coefficient = .993208

X-axis file: r12_heatflux2
Y-axis file: r12_freq2



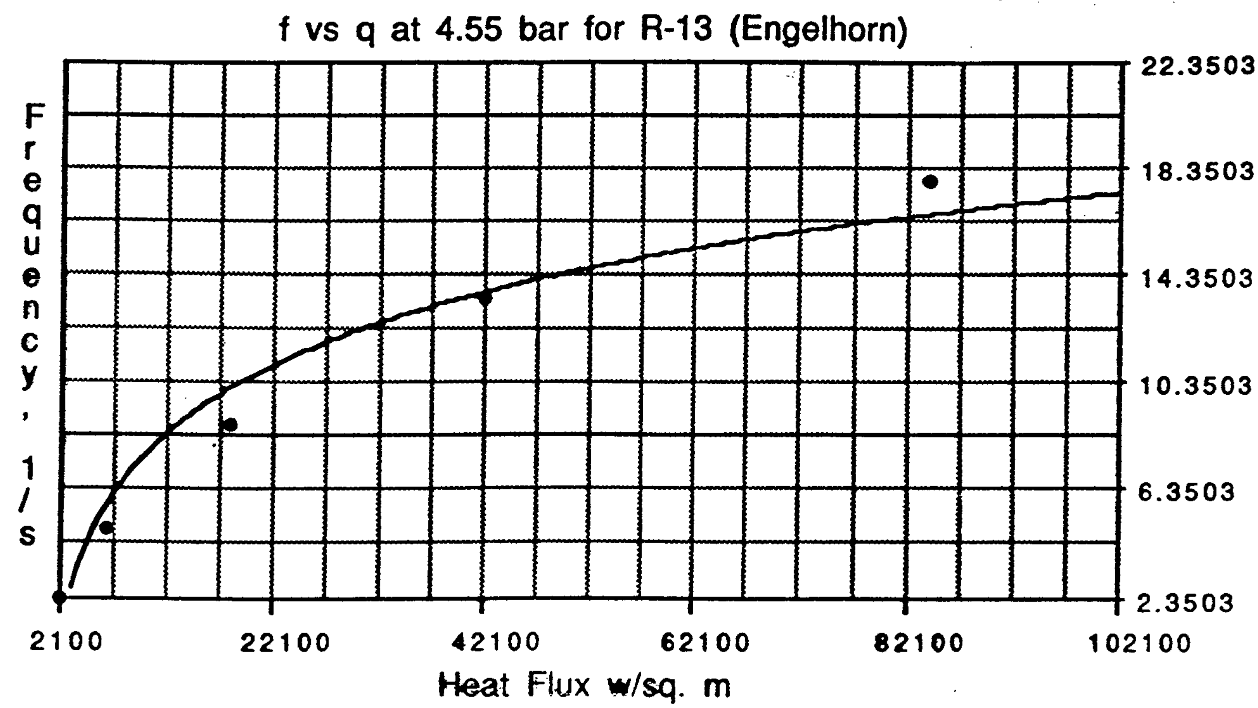
Report Created: 04-17-1996 11:43:38 AM

Power Curve Fit
Pts Plotted = 9 Offscale Pts = 0

Regression Equation:
Y = 1.15874E-03 X ^ .93721

Correlation Coefficient = .99093

X-axis file: r13_heatflux_1
Y-axis file: r13_freq_1



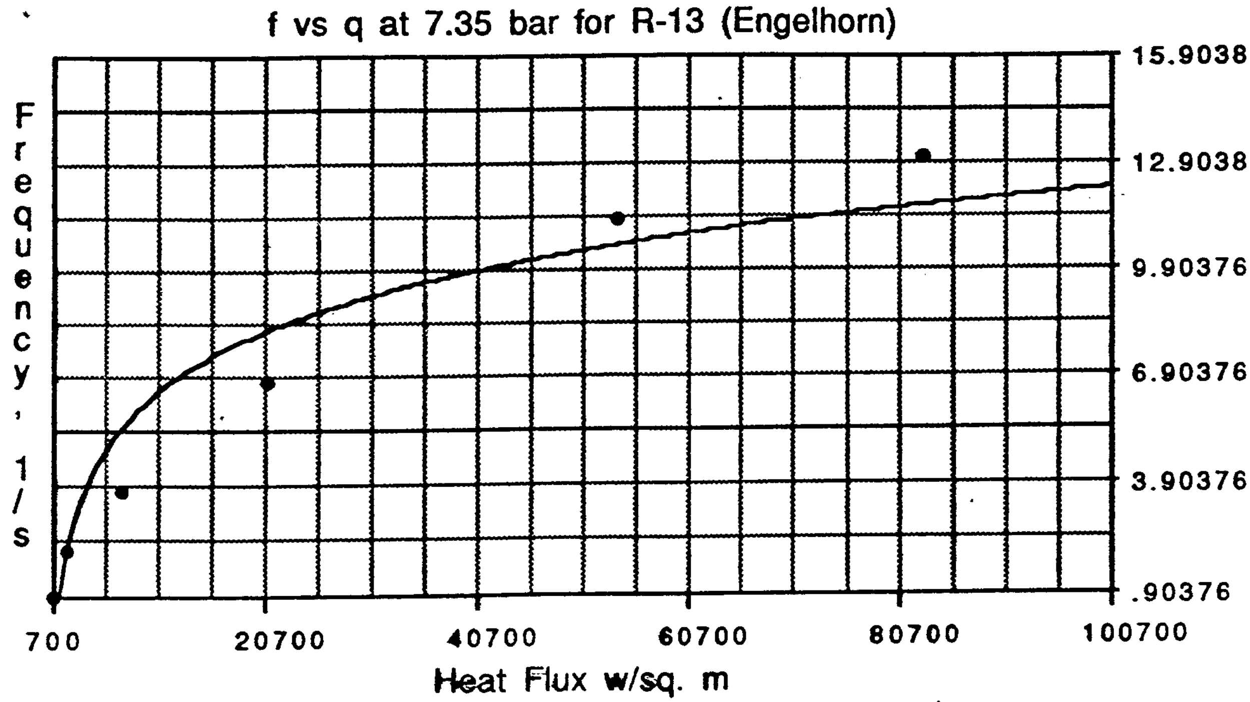
Report Created: 04-17-1996 10:13:31 AM

Logarithmic Curve Fit
Pts Plotted = 5 Offscale Pts = 0

Regression Equation:
Y =-31.0799 + (4.20439) LNX

Correlation Coefficient = .981057

X-axis file: r12_heatflux1
Y-axis file: r13_freq1



Report Created: 04-17-1996 10:13:31 AM

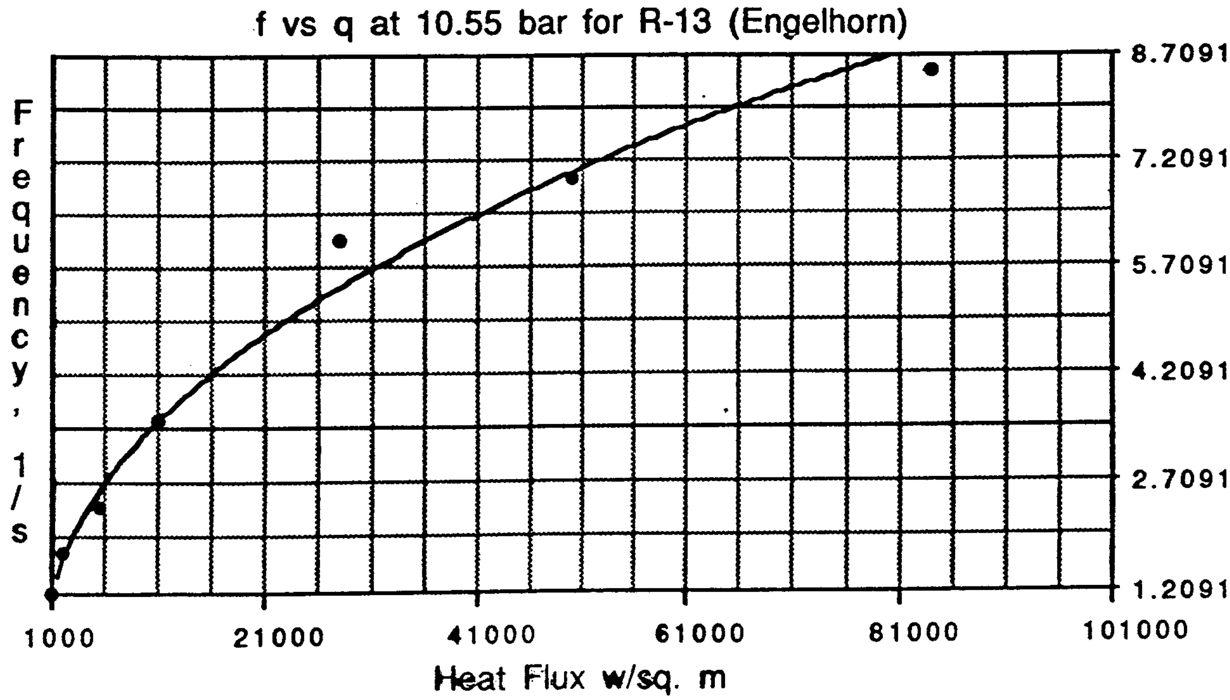
Logarithmic Curve Fit
Pts Plotted = 6

Offscale Pts = 0

Regression Equation:
Y =-17.1613 + (2.54968) LNX

Correlation Coefficient = .960946

X-axis file: r13_heatflux2
Y-axis file: r13_freq2



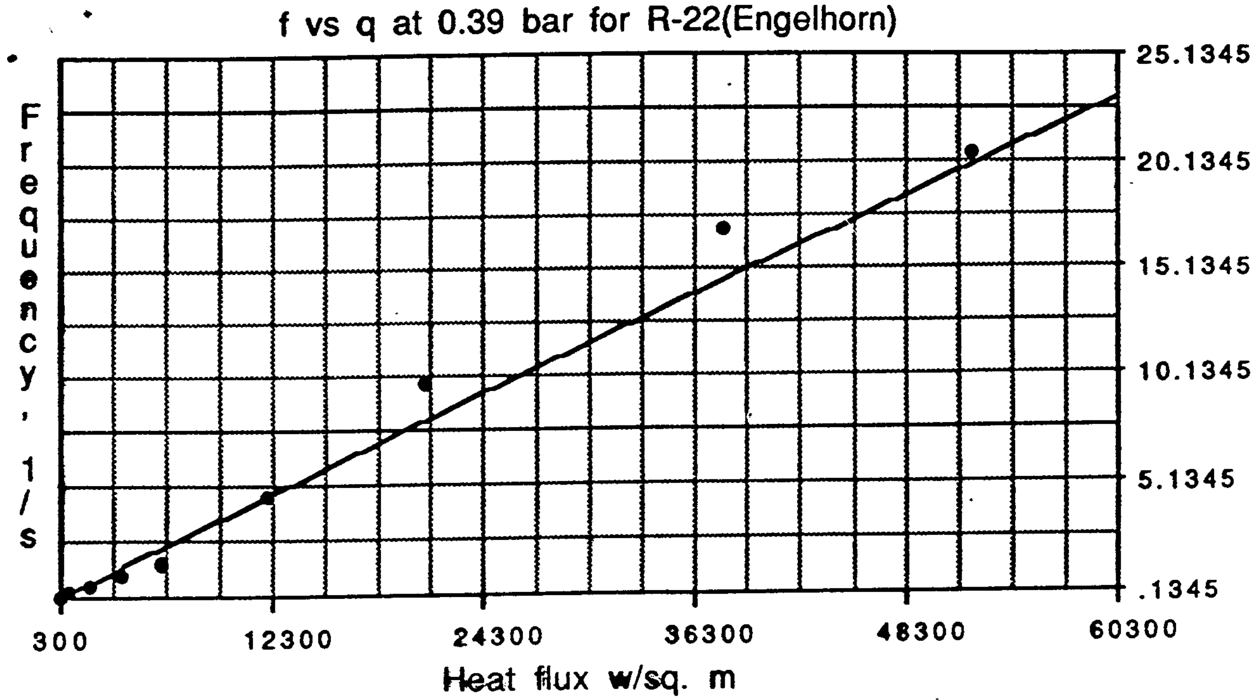
Report Created: 04-17-1996 10:13:31 AM

Power Curve Fit
Pts Plotted = 7 Offscale Pts = 0

Regression Equation:
Y = 5.35501E-02 X ^ .450906

Correlation Coefficient = .996364

X-axis file: r13_heatflux3
Y-axis file: r13_freq3



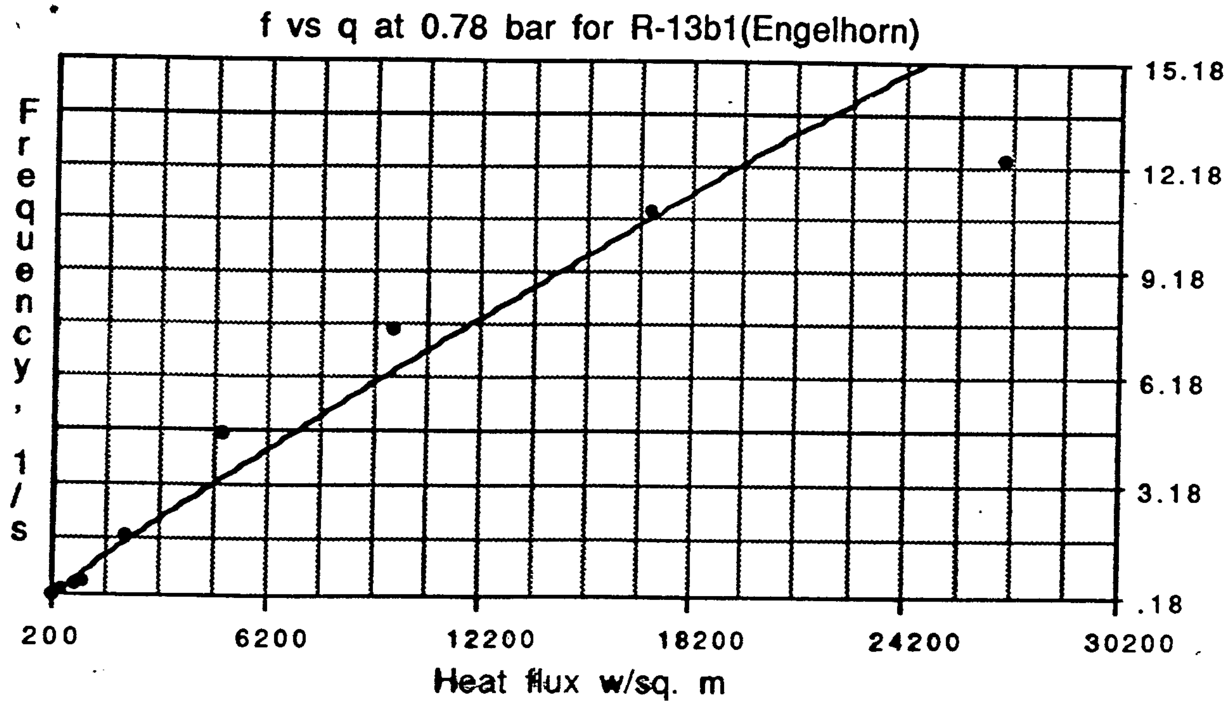
Report Created: 04-17-1996 11:19:54 AM

Power Curve Fit
Pts Plotted = 9 Offscale Pts = 0

Regression Equation:
Y = 3.8682E-04 X ^ .999344

Correlation Coefficient = .99372

X-axis file: r22_heatflux_1
Y-axis file: r22_freq_1



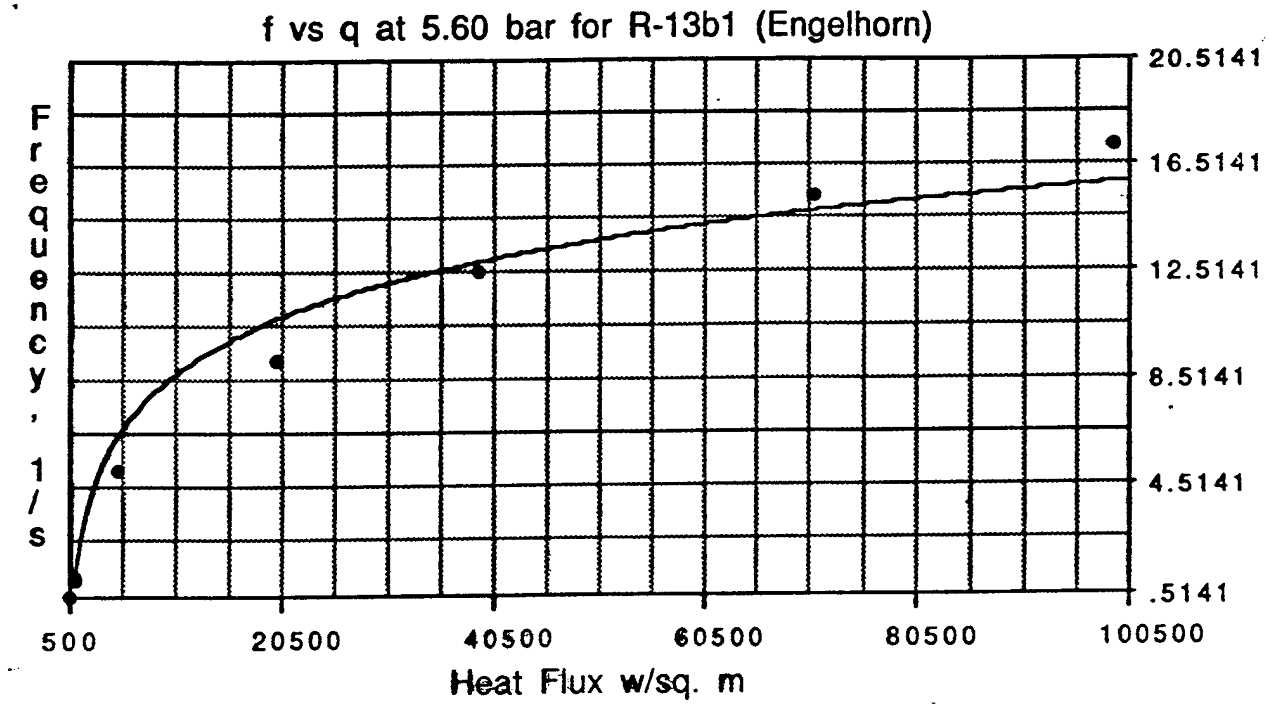
Report Created: 04-17-1996 11:19:54 AM

Power Curve Fit
Pts Plotted = 9 Offscale Pts = 0

Regression Equation:
Y = 1.15874E-03 X ^ .93721

Correlation Coefficient = .99093

X-axis file: r13_heatflux_1
Y-axis file: r13_freq_1



Report Created: 04-17-1996 10:13:31 AM

Logarithmic Curve Fit
Pts Plotted = 7

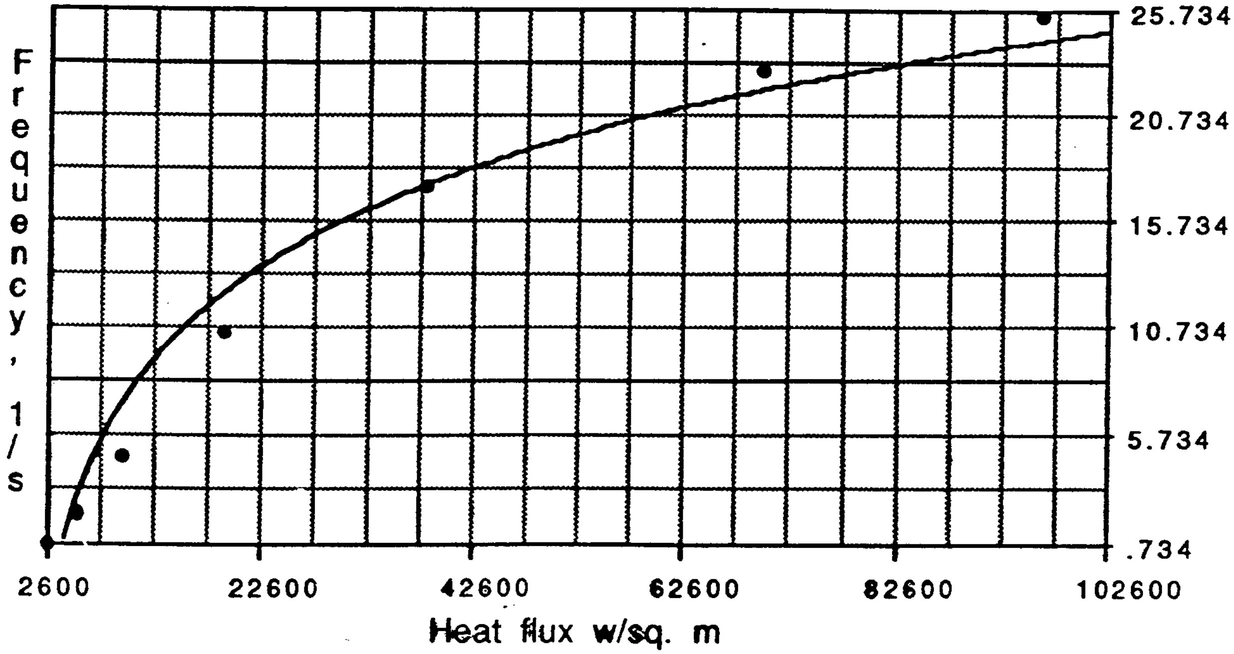
Offscale Pts = 0

Regression Equation:
Y =-20.435 + (3.15063) LNX

Correlation Coefficient = .984194

X-axis file: r13b1_heatflux2
Y-axis file: r13b1_freq2

f vs q at 0.84 bar for R-22(Engelhorn)



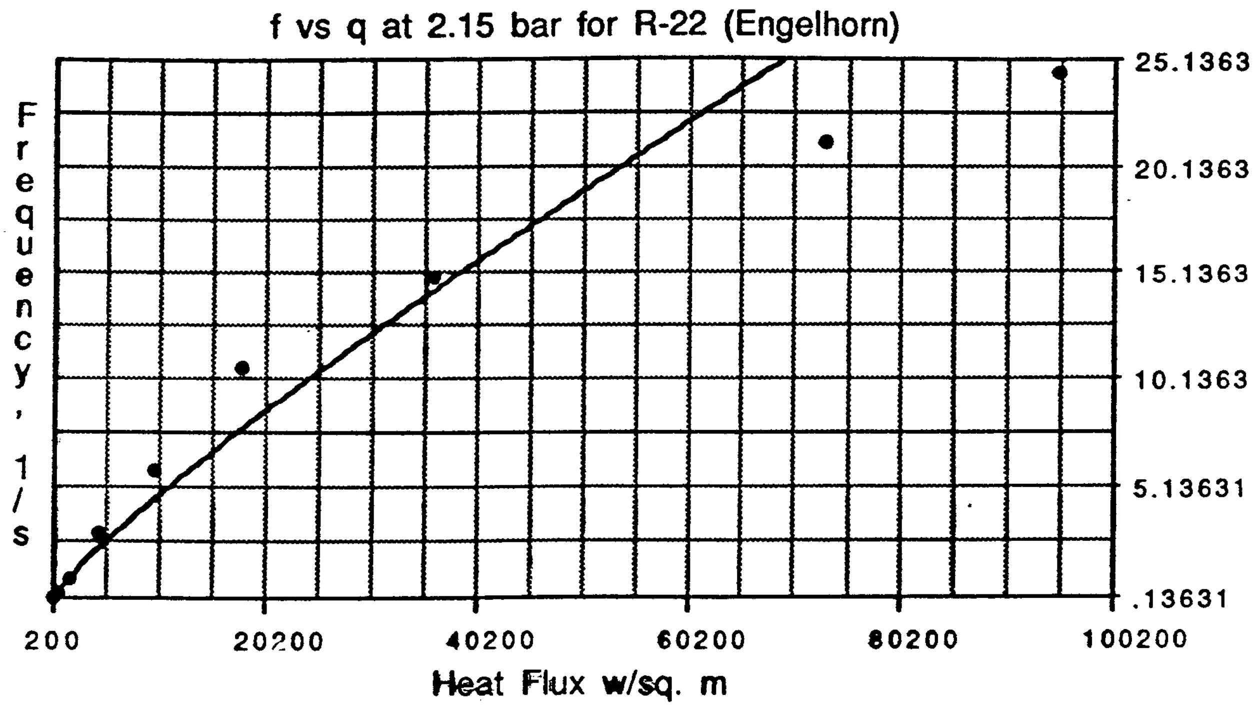
Report Created: 04-17-1996 11:19:54 AM

Logarithmic Curve Fit
Pts Plotted = 7 Offscale Pts = 0

Regression Equation:
Y =-60.4545 + (7.38578) LNX

Correlation Coefficient = .981094

X-axis file: r22_heatflux_2
Y-axis file: r22_freq_2



Report Created: 04-17-1996 10:13:31 AM

Power Cur e Fit
Pts Plotted = 9

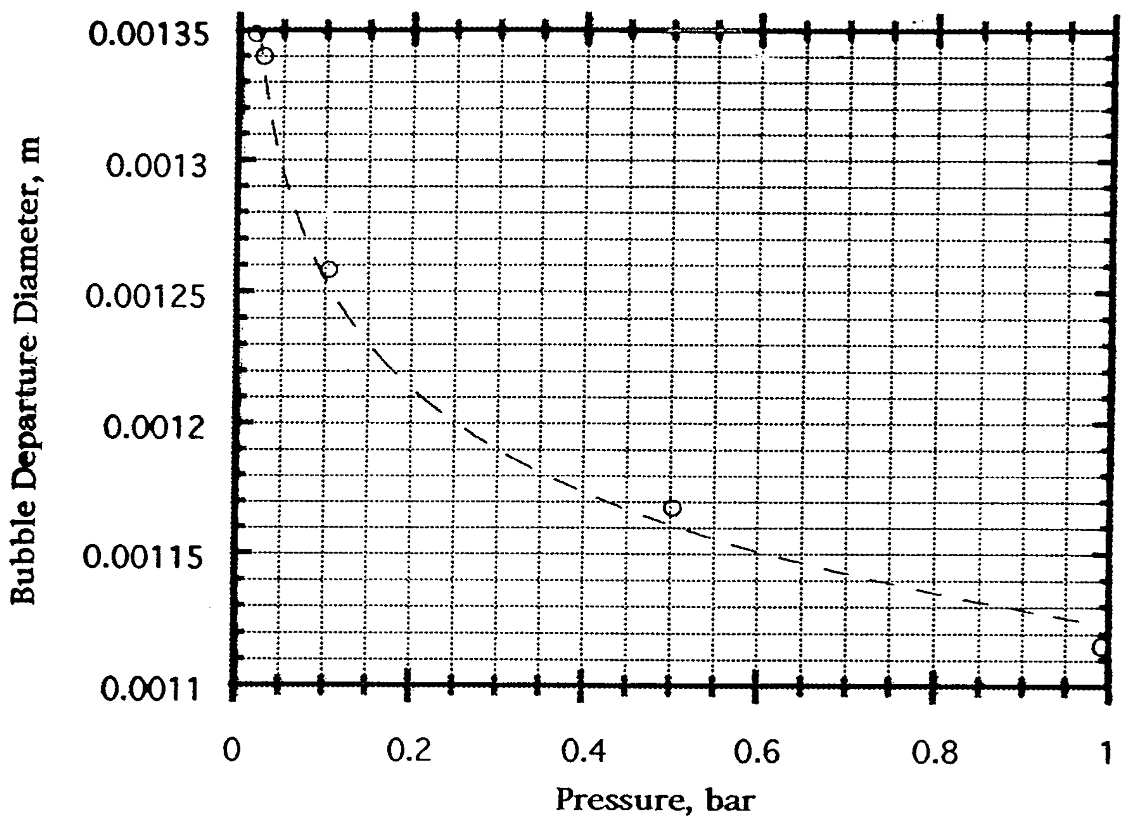
Offscale Pts = 0

Regression Equation:
Y = 1.61784E-03 X ^ .865801

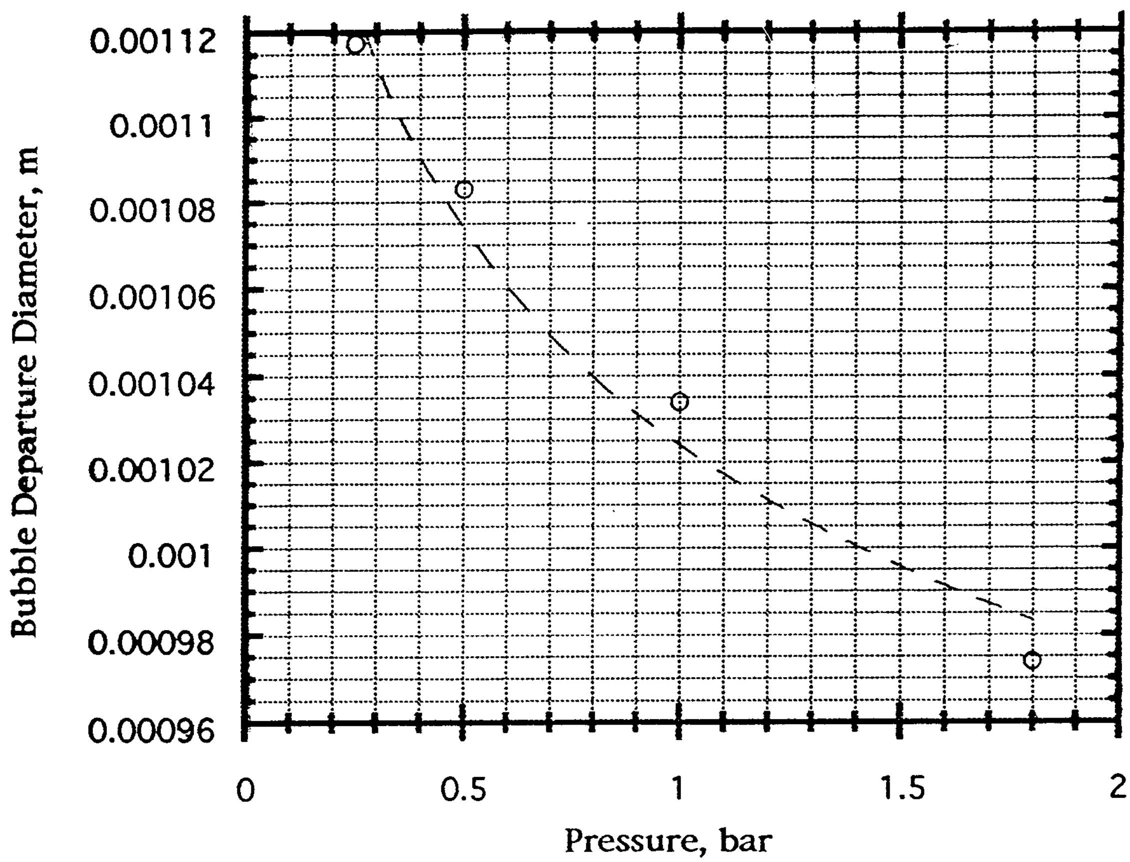
Correlation Coefficient = .992676

X-axis file: r22_heatflux
Y-axis file: r22_freq

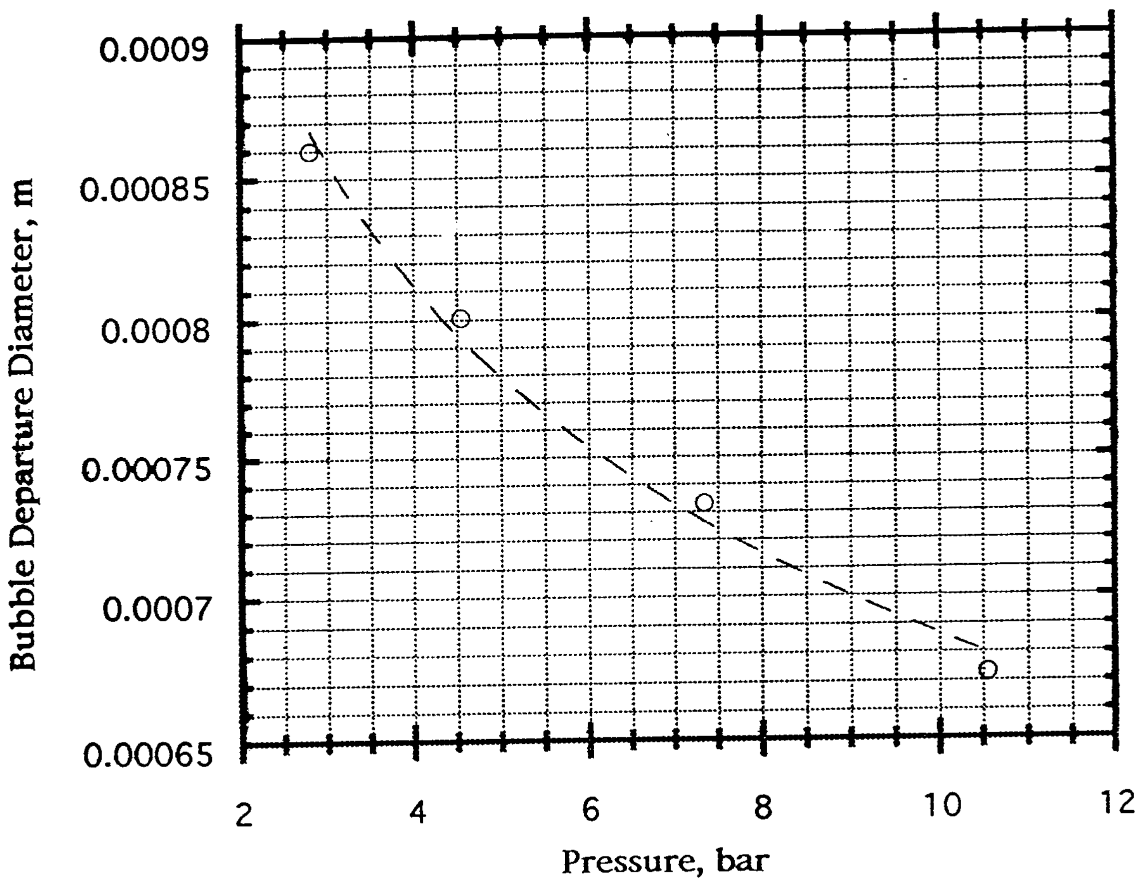
Pressure vs Departure Diameter for R-11
(Data of Engelhorn)



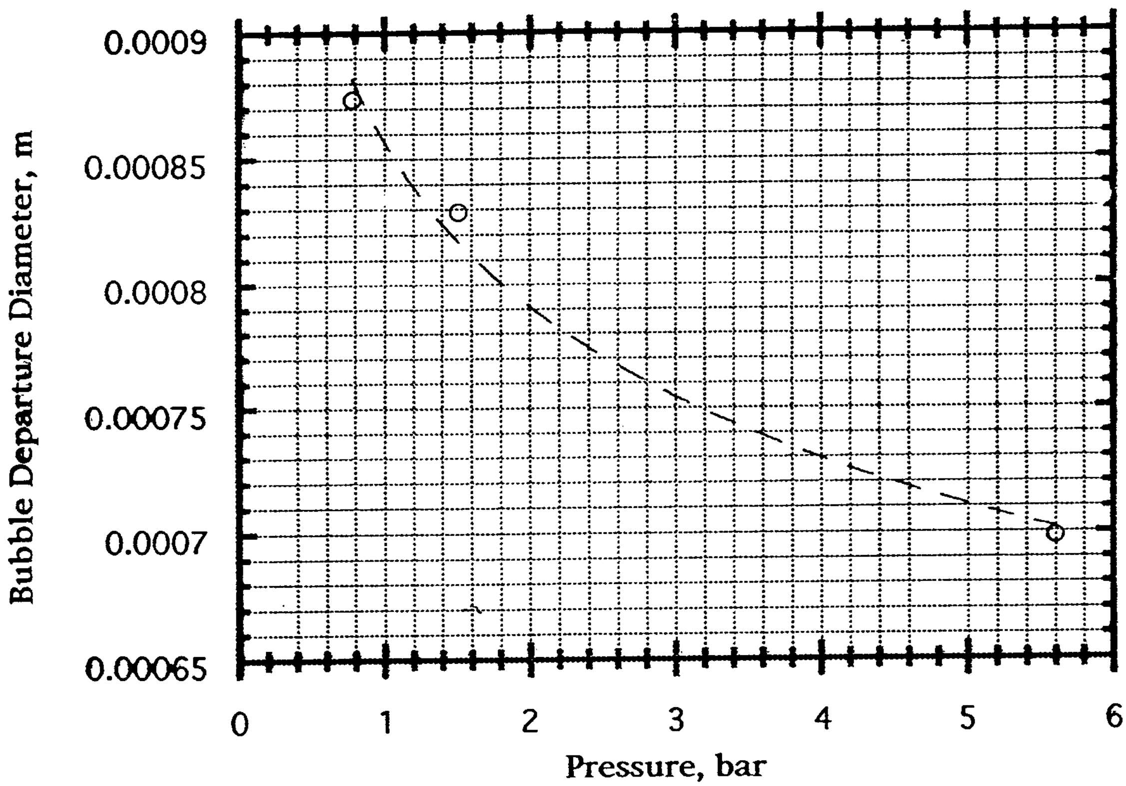
Pressure vs Departure Diameter for R-12
(Data of Engelhorn)



Pressure vs Departure Diameter for R-13
(Data of Engelhorn)



Pressure vs Departure Diameter for R13B1
(Data of Engelhorn)



Pressure vs Departure Diameter for R-22
(Data of Engelhorn)